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APPLICATION

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FIBER OPTIC ATTACHMENT METHOD, STRUCTURE, AND SYSTEM

Background of the Invention

1. Technical Field

The present invention relates to an attachment structure and to a method and system for forming the attachment structure.

2. Related Art

Current methods and systems for effectuating attachment of optical fibers are inefficient and result in complex and costly fiber optic attachment structures. Accordingly, an efficient method and system is needed for effectuating attachment of optical fibers to form simple and economical fiber optic attachment structures.

Summary of the Invention

The present invention provides a method, comprising the following steps of in the indicated sequential order:

melting an end of an optical fiber while the end is above, but not touching, an exposed surface of a substrate such that said end becomes molten end, said optical fiber being substantially optically transparent to laser radiation of a given wavelength;

moving the molten end toward the exposed surface of the substrate until the end makes physical contact with the exposed surface of the substrate, said moving being performed sufficiently fast so that the end is still molten when the end initially makes said physical contact

with the exposed surface of the substrate; and

maintaining said physical contact for a sufficient length of time to enable the end to bond to the exposed surface of the substrate with no intervening matter between the end and the exposed surface of the substrate.

The present invention provides a structure, comprising:

a first substrate having a front surface;

a second substrate having a front surface; and

at least one optical fiber having a first end and a second end, said optical fiber being substantially optically transparent to laser radiation of a given wavelength, said optical fiber being continuous and integral from the first end to the second end, said first end being directly bonded to the front surface of the first substrate with no intervening matter between the first end and the front surface of the first substrate, said second end being directly bonded to the front surface of the second substrate with no intervening matter between the second end and the front surface of the second substrate.

The present invention provides a system, comprising:

means for melting an end of an optical fiber while the end is above, but not touching, an exposed surface of a substrate such that the end becomes molten, said substrate being substantially optically transparent to laser radiation of a given wavelength, said optical fiber

being substantially transparent to laser radiation of a given wavelength;

means for moving the molten end toward the exposed surface of the substrate until the end makes physical contact with the exposed surface of the substrate, said moving being performed sufficiently fast so that the end is still molten when the end initially makes said physical contact with the exposed surface of the substrate; and

means for maintaining said physical contact for a sufficient length of time to enable the end to bond to the exposed surface of the substrate.

The present invention provides an efficient method and system for effectuating attachment of optical fibers to form simple and economical fiber optic attachment structures.

Brief Description of the Drawings

FIG. 1 depicts a front cross-sectional view of an optical fiber moving through a feed nozzle, in accordance with embodiments of the present invention.

FIG. 2 depicts the optical fiber of FIG. 1 with a portion of the optical fiber being engaged by a capillary having side clamps, in accordance with embodiments of the present invention.

FIG. 3 depicts the optical fiber of FIG. 2 above an exposed surface of a first substrate such that an end of the optical fiber is being melted by an electric arc between a pair of electrodes, accordance with embodiments of the present invention.

FIG. 4 depicts the molten end of the optical fiber of FIG. 3 being held in physical contact with the exposed surface of the first substrate after having been moved to the exposed surface of

the first substrate, in accordance with embodiments of the present invention.

FIG. 5 depicts the optical fiber of FIG. 4 being scored at a location along the optical fiber with a sharp wedge to form a crack/flaw in the optical fiber, in accordance with embodiments of the present invention.

FIG. 6 depicts the optical fiber of FIG. 5 such that a portion of the optical fiber is being severed at and above the location at which the optical fiber has been scored, in accordance with embodiments of the present invention.

FIG. 7 depicts the optical fiber of FIG. 6 after having been rotated so as to orient a second end of the optical fiber toward an exposed surface of a second substrate, in accordance with embodiments of the present invention.

FIG. 8 depicts the second end of the optical fiber of FIG. 7 as being molten and being held in physical contact with the exposed surface of the second substrate after having been melted and moved to the exposed surface of the second substrate, in accordance with embodiments of the present invention.

Detailed Description of the Invention

FIG. 1 depicts a front cross-sectional view of an optical fiber **10** having an end **11**, wherein the optical fiber **10** is moving through an anchored (i.e., fixed in space) feed nozzle **12** in a direction **14** toward a substrate **18**, in accordance with embodiments of the present invention. The optical fiber **10** is substantially optically transparent to laser radiation of a given wavelength. The feed nozzle **12** may be embodied in, *inter alia*, jaws. The optical fiber **10** may comprise

glass optical fiber, plastic optical fiber, etc. The optical fiber **10** has any diameter known to be in use (e.g., *inter alia*, 2 to 4 mils diameter) by a person of ordinary skill in the art. The optical fiber **10** is being moved in the direction **14** toward the substrate **18** by moving means **16**, which is any means known to a person of ordinary skill in the art for imparting motion to the optical fiber **10**. For example, the moving means **16** may be a mechanism that grasps the optical fiber **10** and moves the optical fiber **10** through the feed nozzle **12** in a direction **14** toward the substrate **18**. As such, the moving means **16** may be, *inter alia*, a human hand, a wirebond-type machine, robotic means remotely controlled by hardware or software, etc. The feed nozzle **12** serves to constrain the optical fiber **10** to move in the direction **14** toward the substrate **18**. While the direction **14** may be a fixed direction and is depicted in FIG. 1 as being about normally directed toward the front surface **25** of the substrate **18**, the direction **14** may generally be oriented at any angle with respect to the front surface **25** of the substrate **18** (e.g., *inter alia*, 60 to 90 degrees with respect to the plane of the front surface **25**).

The method and system of the present invention will subsequently bond the end **11** to the exposed surface (i.e., front surface **25**) of the substrate **18**. Thus, the end **11** is a terminal portion of the optical fiber **10** that will subsequently become molten and be made to bond to the front surface **25** of the substrate **18**. Hence, the substrate **18** must comprise a material capable of bonding directly to the optical fiber **10** with no intervening matter between the substrate **18** and the optical fiber **10**.

The substrate **18** may comprise a laser source **40** that generates and emits the laser radiation that is substantially optically transparent to the laser radiation of the given wavelength.

For example, the laser source **40** may be comprise, *inter alia*, a Vertical Cavity Surface Emitting Laser (VCSEL) which emits the laser wavelength in a range of 780 to 1550 nanometers (e.g., 980 nanometers) from a region within the substrate **18**. Said region within the substrate **18** may comprise the back surface **24** of the substrate **18**.. A VCSEL is a specialized laser diode emitting laser radiation perpendicular to the back surface **24** and offers low power consumption and overall improved efficiency as compared with conventional edge-emitting laser diodes. The substrate **18** is substantially optically transparent to said laser radiation in an optical path in the substrate **18** between the VCSEL **40** and the front surface **26** of the substrate **18** (see, e.g., optical path **26** in FIG. 4, discussed *infra*).

Referring again to FIG. 1, the present invention may include any type of laser emitting device that is capable of emitting the laser radiation such that the laser radiation may be transmitted from the laser emitting device to the front surface **25**, or alternatively the laser radiation may be emitted by the laser emitting device at the front surface **25**. As seen in FIG. 1, the front surface **25** of the substrate **18** comprises an exposed surface of the substrate **18**. Although the front surface **25** may alternatively receive the laser radiation from above the substrate **18** and may subsequently transmit the laser radiation into the substrate **18** and potentially to the back surface **24**, the substrate **18** will be considered for illustrative purposes as a transmitter of the laser radiation rather than as a receiver of the laser radiation. The substrate **18** may include, *inter alia*, SiGe, GaAs, AlGaAs, or InGaAs.

FIG. 2 depicts the optical fiber **10** of FIG. 1 with a portion of the optical fiber **10** being engaged below the feed nozzle **12** by a capillary **20** having side clamps **22**, in accordance with

embodiments of the present invention. In FIG. 2 with the side clamps **22** in the "relaxed" position shown, the optical fiber **10** continues to be moved (by the moving means **16**) through the feed nozzle **12** in the direction **14** toward the substrate **18** in such a manner that the capillary **20** moves together with the optical fiber **10** in the direction **14**. The side clamps **22** of the capillary **20**, if moved inward in the direction **15** toward the optical fiber **10**, will cause the optical fiber **10** to move the direction **14** relative to the capillary **20** as will been apparent from the description *infra* of FIG. 4.

FIG. 3 depicts the optical fiber **10** of FIG. 2 above the exposed surface **25** of the substrate **18** such that the end **11** of the optical fiber **10** is being melted by any applicable method of applying heat that is known to a person of ordinary skill in the art such as, *inter alia*, by an electric arc **27** between a pair of electrodes **48** with an output power sufficient to melt the end **11**. As a result of the melting, the end **11** becomes molten. The side clamps **22** are being squeezed in the direction **15** toward the optical fiber **10** so as to impart a compressive force to the molten end **11** causing the molten end **11** to move toward the exposed surface **25** of the substrate **18** and make physical contact with the exposed surface **25** of the substrate **18** while the end **11** is still molten. The melting occurs when the end **11** is above the exposed surface **25** and is not touching the exposed surface **25**. After the end **11** has become molten, the electrodes **48** may be moved out of the way so that the molten end **11** can be quickly moved in the direction **14** toward the substrate **18**. Alternatively after the end **11** has become molten, the electrodes **48** may be moved together with the fiber **10** in the direction **14** toward the substrate **18** (but not touching the substrate **18**) such that the tapered shape (which appears conical in FIG. 3) of the electrodes **48**

enables the electrodes **48** to move other optical fibers attached to the substrate **18** out of the way so as to clear a path for movement of the molten end **11** toward the substrate **18**.

In FIG. 3, the height H of the end **11** above the front surface **25** at which the end **11** is being melted must be small enough so that the end **11** could be subsequently moved from the height H in the direction **14** to make physical contact with the substrate **18** and still remain molten upon initially making said physical contact. Thus the minimum value of the height H varies as the inverse of the average transport velocity of the end **11** toward the front surface **25**. However, the minimum value of the height H is further constrained by space considerations. For example, there may be a multitude of such optical fibers (similar to the optical fiber **10**) or other structure bonded to the front surface **25**, and the number and spatial distribution of such optical fibers may interfere with the melting of the end **11**. Thus the existence of said multitude of optical fibers may increase the minimum possible value of the height H. Said multitude of optical fibers may be closely spaced such as having the optical fibers spaced, *inter alia*, 5 to 10 mils apart.

As an alternative embodiment, the substrate **18** may be preheated or otherwise heated in order to assist the reliability of the process of bonding the molten end **11** to the substrate **18**. For example, a large temperature differential between the molten end **11** and the substrate **18** may result in thermal stresses in the substrate **18** and potential fracture and/or cracking of the substrate **18**.

While FIGS. 1-3 show the substrate **18** as having been placed in a fixed position followed by moving the optical fiber **10** toward the substrate **18** in the direction **14**, the substrate **18** may

be alternatively moved into its position below the optical fiber **10** after the optical fiber **10** has been position at the height H.

FIG. 4 depicts the molten end **11** of the optical fiber **10** of FIG. 3 being held in physical contact with the front surface **25** of the substrate **18**, in accordance with embodiments of the present invention. Said physical contact is maintained by further squeezing of the side clamps **22** in the direction **15** toward the optical fiber **10** to maintain a compressive force on the molten end **11** so as to hold the optical fiber **10** in place. Said physical contact is maintained for a sufficient length of time to enable the end **11** to bond to the front surface **25** of the substrate **18** with no intervening matter between the end **11** and the front surface **25**. The portion **36** of the optical fiber **10** is a terminal portion of optical fiber **10**, said terminal portion **36** including the end **11**. Note that the end **11** flares outward in directions approximately parallel to the direction **15**.

After said bond between the end **11** and the front surface **25** has been formed and the optical fiber **10** has a connection at its other end **41** (see FIGS. 7 and 8, described *infra*), FIG. 4 depicts the VCSEL **40** in the substrate **18** as being adapted to emit the laser radiation. Accordingly, the substrate **18** will transmit said laser radiation from the VCSEL **40** in the direction **28** to the front surface **25** of the substrate **18** via laser path **26** within the substrate **18**. The laser path **26** is substantially optically transparent to the laser radiation of the given wavelength. The laser radiation may subsequently enter the end **11** of the optical fiber **10** and then propagates through the optical fiber **10** away from the front surface **25**. Alternatively as stated *supra*, the VCSEL **40** may be replaced by a laser source such as a laser source emits the laser radiation from the front surface **25** into the end **11** of the optical fiber **10**.

FIG. 5 depicts the optical fiber **10** of FIG. 4 being scored at a location **30** along the optical fiber **10** with a sharp wedge **34** to form a crack/flaw **32** in the optical fiber **10**, in accordance with embodiments of the present invention. The crack/flaw **32** may be, *inter alia*, in a plane that is normal to the axis of the optical fiber **10** (i.e., normal to the direction **28**). The crack/flaw **32** may be generated by any other mechanical means such as by a combination of twisting and impact. Note that the capillary **22** has been retracted in the direction **28** relative to the optical fiber **10**.

FIG. 6 depicts the optical fiber **10** of FIG. 5 such that a portion **37** of the optical fiber **10** is being severed at and above the location **30** at which the optical fiber **10** has been scored so as to leave a remaining portion **38** of the optical fiber **10**, in accordance with embodiments of the present invention. The remaining portion **38** includes the end **11**. The severing operation is facilitated by the presence of the crack/flaw **32** (see FIG. 5) at the location **30**. The severing operation may be accomplished by any method known to one of ordinary skill in the art such as breaking away, twisting away, snapping away, sharp impact at an angle that causes severing, etc. The severing may occur in the clockwise direction **40**, or alternatively in a counterclockwise direction.

FIG. 7 depicts the optical fiber **10** of FIG. 6 after having been rotated so as to orient another end **41** of the optical fiber **10** toward an exposed surface **45** of a substrate **52**, in accordance with embodiments of the present invention. The substrate **52** includes a front surface (i.e., the exposed surface **45**) and a back surface **44**. The substrate **52** is substantially optically transparent to said laser radiation at locations within the substrate **52** through which the laser

radiation propagates. The substrate **52** is bondable with the end **41** of the optical fiber **10** in the same manner as the substrate **18** is bondable with the end **11** of the optical fiber **10** (e.g., with no intervening matter between the end **41** and the exposed surface **45**). The substrate **52** may include, *inter alia*, SiGe,GaAs, AlGaAs, or InGaAs.

Rotating the optical fiber **10** may be accomplished, *inter alia*, by concurrently rotating the capillary **20** (see FIG. 6) clockwise or counterclockwise about the axis defined by the direction **28**, in concert with moving the substrate **18** in the direction **49**, and in further concert with moving the capillary **20** (see FIG. 6) in the direction **14**, so that the minimum bend radius of the optical fiber **10** is not disturbed. Any equipment known to a person of ordinary skill in the art may be used to perform the aforementioned concurrent motions. The optical fiber **10** is typically very thin and is thus easy to bend. Rotating the optical fiber **10** is a special case of orienting the optical fiber **10** in any manner so that the end **41** of the optical fiber **10** is facing the exposed surface **45** of the substrate **52**.

While FIGS. 5-7 depict the scoring and severing of terminal portion **37** of the optical fiber **10** prior to said rotating of the optical fiber **10**, the terminal portion **37** of the optical fiber **10** may alternatively be scored and severed after the optical fiber **10** has been rotated. On the other hand, if the optical fiber **10** has the desired length to begin with, then the scoring and severing steps of FIGS. 5 and 6, respectively, are unnecessary and may be omitted.

FIG. 7 also shows the end **41** being melted by electrodes **48** with an associated arc **46** in the same manner as the end **11** is melted by electrodes **24** with the arc **27** (see FIG. 3) as described *supra*. The capillary **50** with side clamps **51** in FIG. 7 has the same functionality as the

capillary **20** with side clamps **22** in FIG. 3. The purpose of melting the end **41** is to subsequently bond the molten end **41** to the front surface **45** of the substrate **52** in the same manner as the end **11** was bonded to the front surface **25** of the substrate **18** as described *supra.*

FIG. 8 depicts the molten end **41** of the optical fiber **10** of FIG. 7 being held in physical contact with the front surface **45** of the substrate **52**, in accordance with embodiments of the present invention. Said physical contact is maintained by squeezing the side clamps **51** in the direction **55** toward the optical fiber **10** to maintain a force on the molten end **41** in the direction **14**. Said physical contact is maintained for a sufficient length of time to enable the end **41** to bond to the front surface **45** of the substrate **52** with no intervening matter between the end **41** and the front surface **45**. The portion **57** of the optical fiber **10** is a terminal portion of optical fiber **10**, said terminal portion **57** including the end **41**.

The VCSEL **40** in the substrate **18** may emit the laser radiation as described *supra* in conjunction with FIG. 4, and said laser radiation enters the end **11** of the optical fiber **10** and then propagates through the optical fiber **10** to the end **41**. The front surface **45** of the substrate **52** is adapted to receive said laser radiation from the end **41**, and the substrate **52** is adapted to transmit said laser radiation from the end **41** into the substrate **52**. The laser radiation may be then transmitted (via optical path **56** within the substrate **52**) to any location within the substrate **52** along the optical path **56** including to the back surface **44** of the substrate **52**. It is noted that the optical fiber **10** is continuous and integral from the end **11** to the end **41**.

While FIG. 8 depicts one optical fiber, namely the optical fiber **10**, being continuous and integral between the ends **11** and **41** which are respectively connected to the front surface **25** and

45 of substrate **18** and **52**, there is generally N such optical fibers such that N is at least 1. N may equal 1 or 2, N may be at least 1000, or N may represent thousands or hundreds of thousands of optical fibers.

While the front surfaces **25** and **45** may be coplanar (e.g., in a computer) as depicted in FIG. 8, the front surfaces **25** and **45** may alternatively not be coplanar (e.g., the as with two circuit boards/circuit cards). If the front surfaces **25** and **45** are not coplanar, then the front surfaces **25** and **45** may be parallel to each other, perpendicular to each other, or at any nonzero angle with respect to each other such that said nonzero angle is unequal to 90 degrees.

While the substrate **18** in FIGS. 4-8 was depicted as being comprised by a first device (i.e., a transmitting device such as a VCSEL) and while the substrate **52** was depicted in FIG. 8 as being comprised by a second device (i.e., a receiving device), the substrates **18** and **52** may be comprised be a same device.

While the substrates **18** and **52** may comprise a same substantially optically transparent material, the substrates **18** and **52** may alternatively comprise different substantially optically transparent materials.

While embodiments of the present invention have been described herein for purposes of illustration, many modifications and changes will become apparent to those skilled in the art. Accordingly, the appended claims are intended to encompass all such modifications and changes as fall within the true spirit and scope of this invention.